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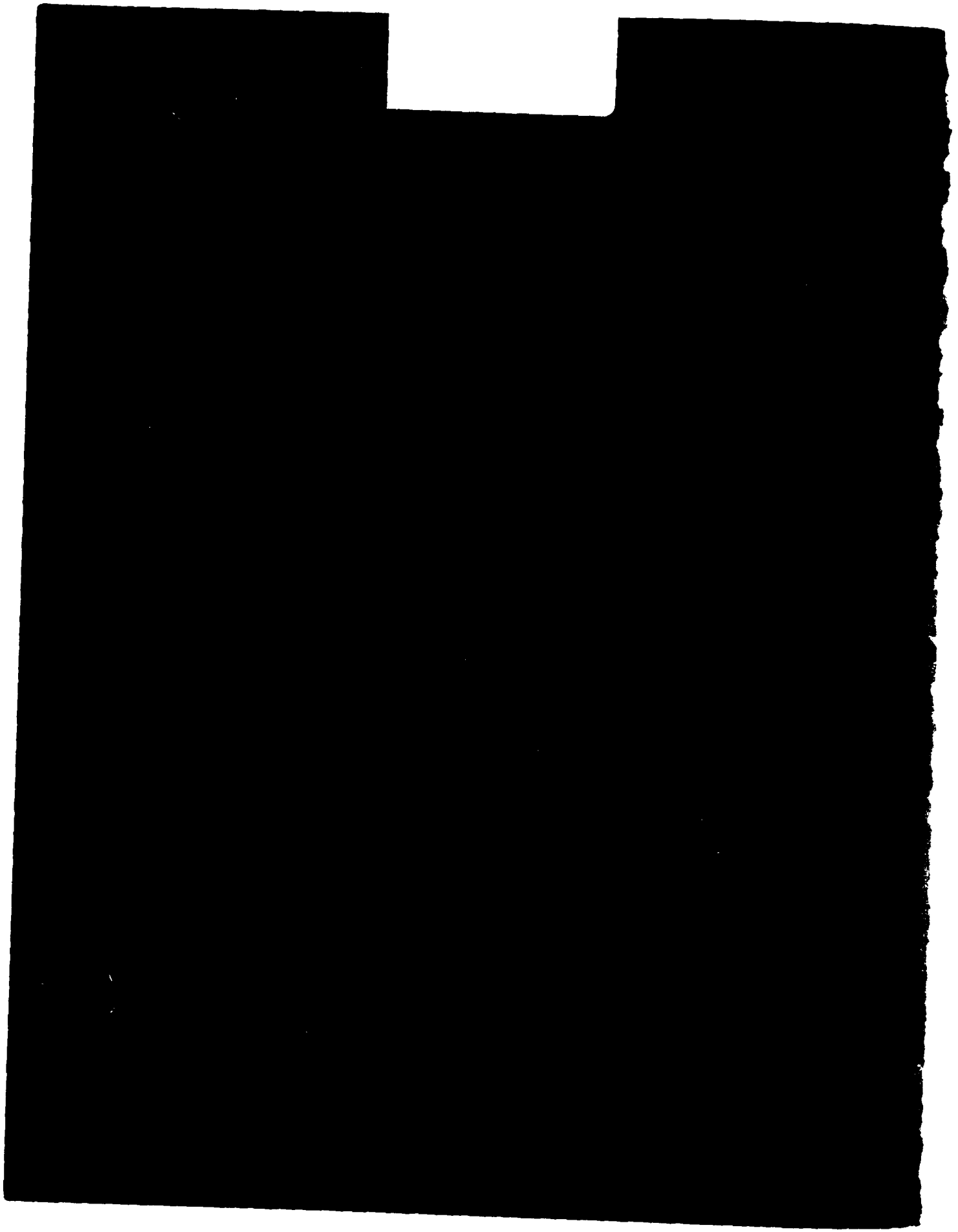

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Estimates of phytoplankton biomass and rates of production can provide a manager with some insight into questions concerning trophic state, water quality, and aesthetics. Methods for estimation of phytoplankton biomass include a gravimetric approach, microscopic enumeration, and chlorophyll a analysis. Strengths and weaknesses of these and other methods are presented. Productivity estimation techniques are discussed including oxygen measurement, carbon dioxide measurements, carbon 14 measurements, and the chlorophyll method. Again, strengths and weaknesses are presented.

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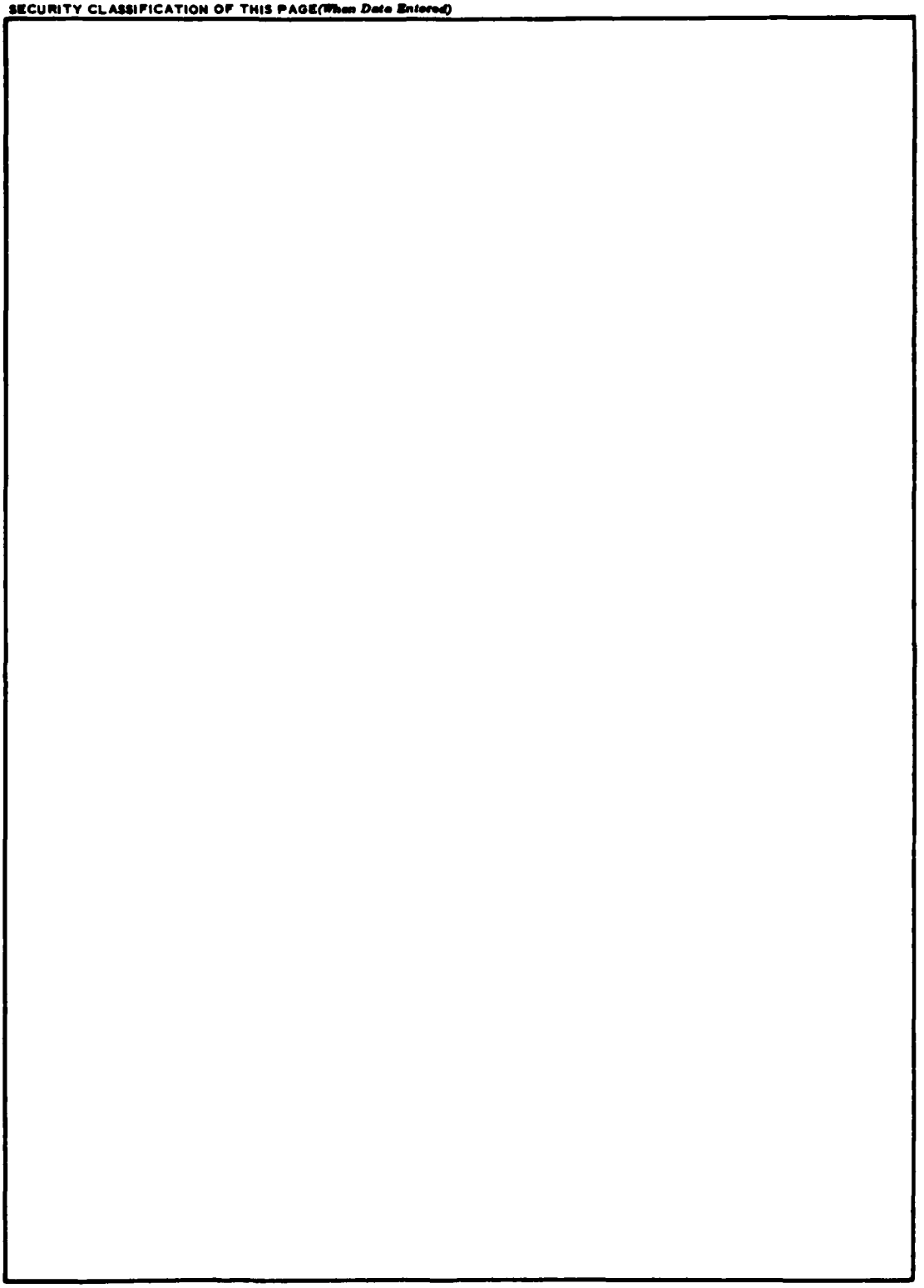


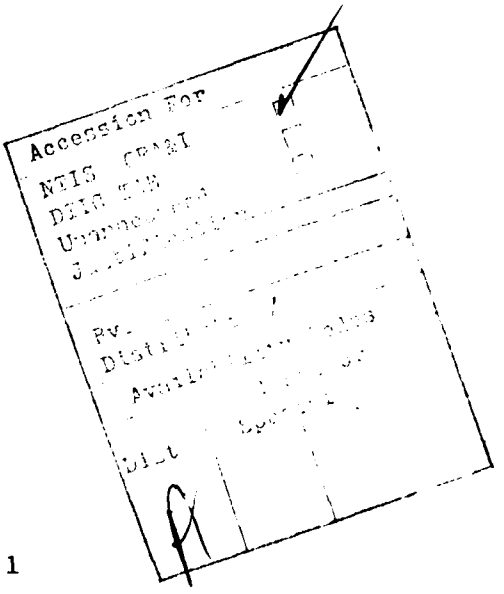
Preface

The study reported herein was sponsored by the Office, Chief of Engineers, U. S. Army, under the Environmental and Water Quality Operational Studies (EWQOS) Program, Task IB.1, Improved Description of Reservoir Ecological and Water Quality Processes. The EWQOS Program has been assigned to the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss., under the purview of the Environmental Laboratory (EL).

The investigation was conducted under Interagency Agreement No. WES-78-12 between the WES and the U. S. Environmental Protection Agency (EPA), Las Vegas, Nev., and the University of Nevada, Las Vegas, Nev. The authors of this report were Messrs. J. J. Janik, W. D. Taylor, and V. W. Lambou.

The study was conducted under the general WES supervision of Dr. Kent Thornton and Mr. Joseph Norton; Dr. Jerome L. Mahloch, Program Manager, EWQOS; Dr. Rex L. Eley, Chief, Ecosystems Research and Simulation Divison; and Dr. John Harrison, Chief, EL.

The Commanders and Directors of the WES during the study and the preparation of this report were COL John L. Cannon, CE, and COL Nelson P. Conover, CE. The Technical Director was Mr. F. R. Brown.



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ESTIMATING PHYTOPLANKTON BIOMASS AND PRODUCTIVITY

Introduction

1. Biomass and productivity measurements provide important information on phytoplankton abundance and growth. Phytoplankton biomass is the amount of algal material present, whereas productivity is the rate at which algal cell material is produced. These data give the reservoir manager a measure of the biological status of the primary producers. Phytoplankton in many lake systems limit the quantitative and qualitative aspects of the higher trophic levels; therefore, knowledge of phytoplankton activities is fundamental to understanding and managing a water body for specific uses. Management questions concerning lake trophic state, water quality, fisheries, and aesthetics can be addressed from these data. Many models, predicting the consequences of nutrients, turbidity, toxicants, and hydrological modifications, require accurate measurements of phytoplankton biomass and productivity. The purpose of this report is to describe and compare methods for estimating phytoplankton biomass and productivity.

Phytoplankton Biomass Techniques

2. Biomass may be defined as the living matter of the various groups of organisms present in an ecological sector at the time of observation. The phytoplankton biomass (standing crop) is the quantity of autotrophic planktonic organisms present in a water body (Steemann-Nielson 1963).

3. Various microscopic, chemical, and biochemical techniques are used to measure the quantity of phytoplankton biomass. The following quantitative measurements can be made using microscopic techniques: numerical abundance, cell volume, cell surface area, and plasma volume.

4. Common chemical and biochemical procedures for measuring biomass include the following parameters: dry weight, ash-free dry weight,

carbon, phosphorus, nitrogen, and chlorophyll a. In the absence of specific analyses, it is possible to estimate particular components indirectly from available data by the use of conversion formulas (Table 1).

5. Direct microscopic examination provides the most useful kind of information (Fogg 1965) and has three basic advantages over other methods. The first is that the algae are observed each time a count is made so that any changes in appearance, size, shape, or aggregation of cells can be recorded. The second is that dead and living cells may be differentiated. The third is that exact information on algal species composition and size distribution is obtainable.

6. Nonmicroscopic determinations of phytoplankton biomass may be impaired by the presence of detrital material, particulate organic matter, zooplankton, and bacteria, but are less time consuming than microscopic counting methods.

Microscopic Methods for Measuring Biomass

Numerical abundance

7. The use of numerical abundance (cells/ml) is of limited value as a measurement of biomass. This is attributable to the variation in cell size within individuals of a species and between different species of phytoplankton. Cell counts do not express these differences since equal numerical value is assigned to each algal cell regardless of size. Paasche (1960) reported that cell numbers tend to be biased towards the smaller, usually more numerous species in the community. Munawar et al. (1974) reported that cell numbers can neither give information about phytoplankton biomass nor can they be correlated with primary production, particularly where algal populations are variable in size; however, cell numbers have been correlated with chlorophyll a. Taylor et al. (1979) found a rank correlation (r_s) between cell numbers and chlorophyll a for 44 eastern and southeastern U. S. lakes to be 0.72 ($P < 0.01$). Munawar et al. (1974) also reported a significant correlation between cell abundance and chlorophyll a ($r = 0.59$, $P < 0.01$).

Cell volume (biovolume)

8. Determination of cell volume (μm^3 per individual or colony) provides a measure of the phytoplankton biomass (mg fresh weight/m^3), assuming that the specific weight of algae is approximately unity. This measurement of standing crop is widely accepted in quantitative surveys (Rodhe et al. 1958, Nauwerck 1963, Munawar and Nauwerck 1971). The appropriate dimensions of at least 25 randomly selected cells are measured, and the volume of each of the measured cells is calculated, from which the mean cell volume is derived (Smayda 1978). The mean cell volume should not be calculated from the average linear dimensions of the individual cells. Cell volumes are usually reported in $\mu m^3/l$ or $\mu m^3/m^3$. Simple geometric formulae may be used to compute the cell volumes, although some phytoplankton cells may have to be subdivided into several shapes because of their complex geometric configurations. Cell volumes are computed by simply integrating the volumes calculated for each form. Standard volumes from published sources should be used with great care in these calculations since differences in cell dimensions vary considerably from one lake to another and even seasonally from the same lake.

9. Results of phytoplankton surveys expressed in terms of biovolumes may tend to overemphasize the importance of the larger forms as producers (Paasche 1960). The small nannoplankton generally assimilate much more carbon per unit of biomass than do the larger forms (Findenegg 1965).

10. Cell volumes generally provide good correlations with other biomass and productivity parameters. Munawar et al. (1974) reported that cell volume was better correlated to chlorophyll a and photosynthesis rates than to cell surface area and numerical abundance. Taylor et al. (1979), however, reported better Spearman rank correlations ($P < 0.01$) with cell numbers and chlorophyll a than with biovolumes and chlorophyll a ($r_s = 0.72$ and 0.66, respectively).

Cell surface area

11. Cell surface area (μm^2) provides a better method of estimating standing crop than does numerical abundance; however, it is not as widely

used or as quantitative as cell volume (Munawar et al. 1974). Cell surface area is important since it represents the assimilative area for nutrients. The area computation is similar to the method used in computing cell volumes.

Plasma volume

12. The measurement of plasma volume (μm^3) has been suggested as a more accurate method than cell volume to estimate standing crop (Paasche 1960). Plasma volume is restricted to the cytoplasm in which the chloroplasts are embedded, thus excluding the vacuoles. This method has limited acceptance in phytoplankton surveys because of the difficulty in quantifying the volume of the cytoplasm in algal cells (Smayda 1965).

Chemical and Physical Methods for Measuring Biomass

Dry weight

13. Dry weight is determined by drying a sample until a constant weight is obtained (Weber 1973). Results are usually reported in µg/l. This method provides a rapid estimate of biomass, but errors occur because delicate algal cells may be disrupted on the filter surface with a subsequent loss of cell material, and algal cells retain a variable amount of residual water after the drying process. Most investigators dry their samples at 105°C; other drying temperatures have been used, but the conversion or comparison of these results is difficult.

Ash-free dry weight

14. Ash-free dry weight is calculated by subtracting the ash content from the dry weight. Results are usually reported in µg/l.

15. This method is preferable to dry weight as a measure of algal biomass when comparisons involving mixed assemblages of species are made. This is due to the variable ash content in planktonic algae, e.g., 50 percent ash in diatoms and 5-20 percent ash in green algae (Nalewajko 1966). Carbon content is often employed as a basis for production rates of phytoplankton populations and is normally in the range of 53 $\pm$ 5% of the ash-free dry weight (Lund and Talling 1957). Additional conversion formulas are given in Table 1.

Chlorophyll a Analysis

16. Chlorophyll a is the predominant chlorophyll pigment in planktonic algae and assumes considerable importance in productivity studies and standing crop estimates. The speed and the simplicity of chlorophyll a analysis are the two main reasons that this method is the most popular for estimating standing crop (Strickland 1960). Results are usually reported in µg/l. The analysis is far less time consuming than are the microscopic "counting" methods. It does not, however, furnish information on algal species and size composition. This method of estimating biomass is also faced with certain problems: pigment extraction is not always complete; chlorophyll content varies with the age and light or shade adaptation of the population; relative pigment composition of various phytoplankton groups is not always constant; and degradation products may be included with active chlorophyll by ordinary extraction processes.

17. Chlorophyll a data are valuable for the rapid comparison of productivity in different bodies of water and are especially informative when used in conjunction with other biomass parameters (Fruh et al. 1966).

Carbon

18. The quantity of carbon present in algal cells provides a satisfactory method for measuring standing crop. The relative amount of carbon present in algal cells on an ash-free organic matter basis is fairly constant. Ryther (1954) has calculated the amount to be 45-55 percent in marine forms. The values for freshwater forms are similar. Table 1 presents additional relationships.

Phosphorus

19. Phosphorus (P) in the form of cellular phosphorus or as total water phosphorus has been used to estimate phytoplankton standing crop. The quantity of cellular phosphorus is quite variable; the amount absorbed by growing phytoplankton and the phosphorus content of resulting cells depends on the phosphorus content of the surrounding medium. Another problem is that plants have the ability to store the phosphorus

in excess of normal requirements (Mackereth 1953), a process termed luxury uptake. Thus, the final phosphorus content of an algal cell depends upon the growth history of the plant and the growth medium. Standing crop estimates from P are gross approximations. The relationship of cell carbon to cell phosphorus is (Strickland 1960):

$$\text{Cell Carbon (mg)} = \text{Cell Phosphorus (mg)} \times 49(\pm 15)$$

20. Various authors have developed regression equations for predicting chlorophyll *a* concentrations as a function of phosphorus (Carlson 1977; Dillon and Rigler 1974; Jones and Bachmann 1976). Kalff and Knoechel (1978) presented a regression equation that provides a mechanism for estimating mean summer biomass from mean summer total phosphorus lake data according to the following relationship:

$$\text{Biomass } (\mu g/m^3) = 1.206 \log \text{ phosphorus } (mg/m^3) + 1.635$$

where $r = 0.84$, $n = 28$, and $p < 0.001$. Additional conversions from phosphorus to biomass via chlorophyll *a* and carbon are given in Table 1.

Nitrogen

21. This element, like phosphorus, can vary according to the amount present in the medium from which the plants are grown and can provide only an approximate estimation of standing crop. Strickland (1960) determined the following relationships for marine phytoplankton:

$$\text{Cell carbon (mg)} = \text{cell nitrogen (mg)} \times 6(\pm 2)$$

and

$$\text{Chlorophyll } a \text{ (mg)} = \frac{\text{cell nitrogen (mg)}}{7(\pm 3)}$$

Phytoplankton Productivity Techniques

22. Primary productivity is the rate at which energy is stored by photosynthetic and chemosynthetic activity of producer organisms (algae) in the form of organic substances that can be used as food materials (Odum 1971). Respiration, on the other hand, is the use of organic substances by organisms to provide the energy they need for their life processes. Several component categories have been identified and found to be useful in understanding energy flows in aquatic systems.

23. The basic equation used to describe photosynthesis and aerobic respiration is

$$6CO_2 + 6H_2O \underset{\text{energy output}}{\overset{\text{energy input}}{\rightleftharpoons}} C_6H_{12}O_6 + 6O_2$$

Carbon dioxide is the primary carbon source taken from the environment and incorporated into cell mass through the use of solar energy. One of the byproducts of this reaction is O_2, which is released into surrounding environment and used to satisfy respiratory demands of the organism itself. Aerobic respiration utilizes stored food and O_2 and produces CO_2 and water. Consequently, both photosynthesis and respiration can be measured by observing the increase of O_2 in the aquatic environment diurnally (or under conditions where light is present) and the decrease in O_2 nocturnally (or under conditions where light is not present). These processes can also be measured by observing the decrease in CO_2 in the aquatic environment diurnally and the increase of CO_2 nocturnally.

24. If the general equation for production/respiration proceeds exactly as given, the CO_2/O_2 budget should exhibit a ratio of one. There are other processes occurring in aquatic systems that alter the CO_2 budget(anaerobic respiration will release CO_2 without consuming O_2).

25. Gross primary productivity is defined as the total rate of

photosynthesis, including the organic matter used in respiration during the measurement period. It is also known as "total photosynthesis" or "total assimilation" (Odum 1971). Net primary productivity is the storage rate of organic matter in plant tissues in excess of the respiratory utilization by the plants during the period of measurement. It is also known as "apparent photosynthesis" or "net assimilation" (Odum 1971). Net community productivity is the storage rate of organic matter not used by autotrophs and heterotrophs (i.e., net primary production minus heterotrophic consumption) during the period under consideration.

26. There are four general methods to measure phytoplankton primary productivity. These involve the measurement of (1) changes in the O_2 content of water, (2) changes in the CO_2 content of water, (3) incorporation of carbon-14 tracers into the organic matter of phytoplankton, or (4) chlorophyll. In general, the values for gross production will depend on how production is measured. According to Rich and Wetzel (1978),

> Oxygen not reduced to water because of anaerobic respiration will appear as net production but not as respiration and gross photosynthesis by the oxygen method will underestimate the flow of energy through the ecosystems. Carbon methods will correctly estimate gross carbon uptake but will underestimate an accumulation of reducing power on non-carbon substrates by anaerobic metabolism and overestimate the flow of energy through the system.

Sources for error in the use of the carbon method include respiratory losses of CO_2 and the secretion of soluble organic products of photosynthesis. The carbon method is far more sensitive and better suited for use in oligotrophic waters than the O_2 method. Fogg (1965), however, recommends the O_2 method in eutrophic waters.

Oxygen measurements

27. This technique provides estimates of net and gross productivity as well as respiration. Samples of phytoplankton can be incubated in situ in clear and dark bottles and changes in their O_2 content can be measured over time. Another approach is to measure changes in O_2 concentration diurnally and nocturnally in the aquatic environment. Initial concentrations of dissolved O_2 (C_1) can be expected to be reduced

to a lower value (C_2) by respiration under conditions where light is not present and to be increased to a higher concentration (C_3) by photosynthesis under conditions where light is present. The following measurements can be calculated with the technique:

a. Respiratory activity = $(C_1 - C_2)$.

b. Net primary production = $(C_3 - C_1)$.

c. Gross primary production $(C_3 - C_2) = (C_3 - C_1) + (C_1 - C_2)$.

Results can be expressed as the amount of carbon fixed (as a result of photsynthesis) per unit volume of water per hour or day.

28. There are advantages and disadvantages to measuring O_2 changes in bottles as opposed to measuring those actually occurring in the environment. Any method that encloses water samples in bottles involves a drastic alteration in the environment: (1) the normal turbulence of the water is reduced to such low levels that important components of the community settle out and collect on the glass surface of the bottle where supplies of CO_2 and other nutrients are likely to be transported to the site at reduced rates; buoyant forms float to the surface; (2) motile members of the community are likely to swim either toward or away from the light (depending on its intensity), and when they reach the wall of the bottle, they may become attached there or may perish; and (3) the large increase in solid surface presented by the walls of the bottle enhances the growth of bacteria and fungi, generating an unnatural biomass of these components and an equally unnatural respiration rate as computed from the dark bottle data. Bunt (1965) found that respiration was not the same for all species of phytoplankton in both light and dark bottles. Differences in daytime and nighttime respiration of autotrophs and heterotrophs could affect the accuracy of estimates of productivity obtained by measuring O_2 concentration changes in the aquatic environment. If the exchange of O_2 with the atmosphere is significant, it should be corrected for in determining productivity by measuring changes in O_2 concentrations in the aquatic environment.

Carbon dioxide measurements

29. As with the O_2 method, changes in CO_2 can be measured in clear and dark bottles incubated in situ, or diurnal and nocturnal changes can

be measured in the aquatic environment. Both production and respiration can be estimated from these changes.

30. In aquatic systems the pH of water is a function of the dissolved CO_2 content and changes in pH are usually measured and then converted to CO_2. A calibration curve for the water in a particular system must be prepared because the pH and CO_2 content are not linearly related and the degree of pH change per unit of CO_2 change depends upon the buffering capacity of the water. Thus, one unit of CO_2 removed by photosynthesis will bring about a pH increase in soft water from a mountain stream greater than that in well-buffered sea water (Odum 1971). Detailed instructions for calibration curves are given by Beyers et al. (1963). Most of the discussion relative to the use of O_2 measurements is also pertinent to the use of CO_2 measurements.

Carbon-14 measurements

31. With this technique the incorporation of carbon-14 tracer into the organic matter of phytoplankton during photosynthesis is used to measure primary production. There is uncertainty as to whether the radiocarbon method measures net or gross photosynthesis, or a rate between the two (Steemann-Nielsen 1963 and Yentsch 1963). Ryther (1954) has shown that it measures a quantity closer to the net photosynthetic rate.

Chlorophyll method

32. Chlorophyll has been described previously as a measure of biomass; however, it can also be used to measure productivity. The use of this method is not as widespread as the other methods. Many of the problems mentioned in the biomass techniques section also affect the measurement of productivity. An additional problem is that algae species tend to be sun or shade adapted according to the light intensity that the algae experience. Shade-adapted plants tend to have a higher concentration of chlorophyll than do sun-adapted plants.

33. This method requires the measurements of the assimiliation ratio (the rate of production per gram of chlorophyll, as grams O_2 per hour per gram chlorophyll), the chlorophyll concentration, and surface light radiation. Ryther and Yentsch (1957) found that marine

phytoplankton at light saturation have a reasonably constant assimilation ratio of 3.7 grams of carbon assimilated per hour per gram of chlorophyll. Calculated production rates based on this ratio and on chlorophyll-light measurements were very similar to those obtained by the light- and dark-bottle oxygen method.

Algae-Related Conversion Formulas

34. Conversion formulas used to calculate particular biological and chemical components from available data are listed in Table 1. The table gives the formula, limitations and qualifications, and a reference for each conversion listed. These conversion formulas should be used with utmost caution because of variability in the relative chemical composition of biological samples. The variability is dependent upon a number of biological, historical, and environmental conditions. Only rough estimates can be expected for many factors; however, if the uncertainties of the factors are fully realized and the inherent errors are appreciated, useful information may be obtained and used.

References

Antia, N. J., C. D. McAllister, T. R. Parsons, K. Stephens, and J. D. H. Strickland. 1963. Further measurements of primary production using a large volume plastic sphere. Limnol. Oceanogr. 8:166-183.

Beyers, R. J., J. Latimer, H. T. Odum, R. B. Parker, and N. E. Armstrong. 1963. Directions for determinations of changes in carbon dioxide concentration from changes in pH. Publ. Inst. Mar. Sci. Univ. Texas. 9:454-489.

Bunt, J. 1965. Measurements of photosynthesis and respiration in a marine diatom with the mass spectrometer and with carbon-14. Nature 207:1373-1375.

Carlson, R. E. 1977. A trophic state index for lakes. Limnol. Oceanogr. 22(2):361-369.

Dillon, D. J. and F. H. Rigler. 1974. The phosphorus chlorophyll relationship in lakes. Limnol. Oceanogr. 19:767-773.

Findenegg, I. 1965. Relationship between standing crop and primary productivity. In: Primary Productivity in Aquatic Environments. C. R. Goldman (ed.). Mem. Ist. Ital. Idrobiol. 18 Suppl., University of California Press, Berkeley. pp. 273-289.

Fogg, G. E. 1965. Algal cultures and phytoplankton ecology. University of Wisconsin Press, Madison, Wisconsin.

Fruh, E. G., H. M. Stewart, G. F. Lee, and G. A. Rohlich. 1966. Measures of eutrophication and trends. J. Wat. Pollut. Control Fed. 38(8): 1237-1258.

Jones, J. R. and R. W. Bachman. 1976. Prediction of phosphorus and chlorophyll levels in lakes. J. Water Pollut. Control Fed. 48(9): 2176-2182.

Kalff, J. and R. Knoechel. 1978. Phytoplankton and their dynamics in oligotrophic and eutrophic lakes. Ann. Rev. Ecol. Syst. 9:475-495.

Lambou, V. W., L. R. Williams, S. C. Hern, R. W. Thomas, and J. D. Bliss. 1976. Prediction of phytoplankton productivity in lakes. In: Proceedings of the Conference on Environmental Modeling and Simulation, EPA 600-9/76-016. pp. 696-700.

Lund, J. W. G. 1964. Primary production and periodicity of phytoplankton. Verh. Int. Ver. Limnol. 15:37-56.

Lund, J. W. G. and J. F. Talling. 1957. Botanical limnological methods with special reference to the algae. Bot. Rev. 23:489-583.

Mackereth, F. J. 1953. Phosphorus utilization by Asterionella foromosa Hass. J. Exp. Bot. 4:296-313.

Mullin, M. M., P. R. Sloan, and R. W. Eppley. 1966. Relationship between carbon content, cell volume, and area in phytoplankton. Limnol. Oceanogr. 11(2):307-311.

Munawar, M. and A. Nauwerch. 1971. The composition and horizontal distribution of phytoplankton in Lake Ontario during the year 1970. In: Proc. 14th Conf. Great Lakes Pes., Int. Assoc. Great Lakes Res. pp. 69-78.

Munawar, M., P. Stadelman and I. F. Munwar. 1974. Phytoplankton biomass, species composition and primary production at a nearshore and midlake station of Lake Ontario during IFYGL. Proc. 17th Conf. Great Lake Res. Internat. Assoc. Great Lakes Res. pp. 629-652.

Nalewajko, C. 1966. Dry weight, ash and volume data for some freshwater planktonic algae. J. Fish Res. Bod. Canada. 23(8):1285-1288.

Nauwerck, A. 1963. The relationships between zooplankton and phytoplankton in Lake Erken. Sumb. Bot. Uppsal. 17(5):1-163.

Odum, E. P. 1971. Fundamentals of Ecology. Third Edition. W. B. Saunders Company, Philadelphia.

Paasche, E. 1960. On the relationship between primary production and standing stock of phytoplankton. J. Cons. Int. Explor. Mer. 26:33-48.

Rich, P. H. and R. G. Wetzel. 1978. Detritus in the lake ecosystem. The Amer. Natur 112(982):57-71.

Rodhe, W., R. A. Vollenweider and A. Nauwerck. 1958. The primary production and standing crop of phytoplankton. In: Perspectives in Marine Biology. A. A. Buzzati - Traverso (ed.). University of California Press, Berkeley. pp. 299-322.

Ryther, J. 1954. The ratio of photosynthesis to respiration in marine plankton algae and its effect upon the measurement of productivity. Deep-Sea Res. 2:134-139.

Ryther, J. H. and C. S. Yentsch. 1957. The estimation of phytoplankton production in the ocean for chlorophyll and light data. Limnol. Oceanogr. 2:281-286.

Smayda, T. J. 1965. A quantitative analysis of the phytoplankton of the Gulf of Panama II: On the relationship between C_{14} assimilation and diatom standing crop. Inter-American Tropical Tuna Commission Bulletin. 9(7):467-531.

Smyda, T. J. 1978. From phytoplankters to biomass. In: Phytoplankton Manual. A. Sournia (ed.). United Nations Educational, Scientific and Cultural Organization, Paris. pp. 273-279.

Soeder, C. J., J. F. Talling, and I. Baak. 1969. Dry weight and ash content. In: A Manual on Methods of Measuring Primary Production in Aquatic Environments. I.B.P. Handbook No. 12. Blackwell Scientific Publications, Oxford and Edinburgh. pp. 18-21.

Spangler, F. L. 1969. Chlorophyll and carotenoid distribution and phytoplankton ecology in Keystone Reservoir, Tulsa, Oklahoma. Ph.D. dissertation. Oklahoma State University.

Steemann-Nielson, E. 1963. Productivity, definition and measurement. In: The Sea, Vol 2. M. H. Hill (ed.). Interscience, New York. pp. 129-164.

Strathman, R. E. 1967. Estimating the organic carbon content of phytoplankton from cell volume or plasma volume. Limnol. Oceanogr. 12(3): 411-418.

Strickland, J. D. H. 1960. Measuring the production of marine phytoplankton. Bulletin No. 122. Fish Res. Board of Canada, Queens Printer, Ottawa, Canada.

Taylor, W. D., L. R. Williams, S. C. Hern, and V. W. Lambou. 11979 Phytoplankton Water Quality Relationship in U. S. Lakes. Part VII. Comparison of some new and old indices and measurements of trophic state. EPA-600/3-79-079. U. S. Environmental Protection Agency, Las Vegas, Nevada.

Verduin, J., L. R. Williams, and V. W. Lambou. 1976. Components contributing to light extinction in natural waters: Method for isolation. U. S. Environmental Protection Agency. National Eutrophication Survey Working Paper No. 369.

Weber, C. I. (ed.). 1973. Biological field and laboratory methods for measuring the quality of surface waters and effluents. EPA-670/4-73-001. National Environmental Research Center Office of Research and Development, U. S. Environmental Protection Agency, Cincinnati, Ohio.

Williams, L. R., V. W. Lambou, S. C. Hern, and R. W. Thomas. 1978. Relationships of productivity and problem conditions to ambient nutrients: National Eutrophication Survey findings for 418 eastern lakes. EPA-600/3-78-002. U. S. Environmental Protection Agency, Las Vegas, Nevada.

Wright, J. C. 1959. Limnology of Canyon Ferry Reservoir. II. Phytoplankton standing crop and primary production. Limnol. Oceanogr. 4(3):235-245.

Yentsch, C. S. 1963. Primary production. Oceanogr. Mar. Biol. Ann. Rev. 1:157-175.

Table 1

Annotated Conversion Table for Algae-Related Measurements*

Conversion	Formula and Comments	Reference
1. Cell volume to biomass	Biomass (mg) = V_{total} (μm^3) × 10^{-9} $\frac{mm^3}{\mu m^3}$ × S	Strickland (1960), Lund and Talling (1957)
	where	
	V_{total} = sum of the volumes for each species, and S is 1.0, the approximate specific gravity of algae	
	Comment: The results of most surveys are expressed in terms of fresh weight (mg) where the approximate specific gravity of algae is assumed to be 1.0.	Rodhe et al. (1958)
2. Dry weight to ash-free dry weight	Ash-free dry weight (mg) = F × dry weight (mg)	
	where	
	F = 0.80 to 0.95 for green algae	Nalewajko (1966)
	F = *0.70 to 0.90 for dinoflagellates*	*Strickland (1960) (marine)*
	F = 0.50 for diatoms	Nalewajko (1966), Soeder et al. (1969)
3. Ash-free dry weight to cell carbon	Carbon (mg) = F × ash-free dry weight (mg)	
	where	
	F has been variously estimated by different workers, i.e.,	
	F = 0.53 ± 0.05	Lund and Talling (1957), Lund (1964)
	F = 0.40 - 0.60	Soeder et al. (1969)
	F = 0.45 - 0.55 for marine algae	Ryther (1954) (marine)
	Comment: Cell carbon is one of the least variable constituents of algal cells. The percentage of carbon varies under unusual conditions, notably when photosynthesis continues under conditions of nitrogen deficiency.	

* Applies to freshwater algae unless noted otherwise.

Table 1 (Continued)

Conversion	Formula and Comments	Reference
4. Dry weight to cell carbon	Carbon (mg) = F × dry weight (mg)	
	where	
	F is variously estimated by different workers and for different classes of algae, i.e.,	
	$F_{\text{diatom communities}}$ = 0.20 - 0.25	Lund (1964), Antia et al. (1963)
	$F_{\text{nondiatom communities}}$ = 0.43 - 0.50	Lund (1964), Verduin et al. (1976)
5. Cell volume to cell carbon (nondiatoms)	$\text{Log}_{10}\ C = 0.76\ \text{Log}_{10}\ V - 0.29$	Mullin et al. (1966) (marine)
	where	
	C is cell carbon in picograms and V is cell volume in μm^3	
	Comment: This formula was developed for use with preserved marine phytoplankton samples. This equation should not be used for diatoms because they have such a large vacuole and lower carbon per unit of cell volume. Conversion number 6 was developed for diatoms.	
6. Cell volume to cell carbon (diatoms)	$\text{Log}_{10}\ C = 0.712\ \text{Log}_{10}\ V - 0.314$	Strathmann (1967) (marine)
	where	
	C is cell carbon in picograms and V is cell volume in μm^3	
7. Algal biomass to carbon	Carbon (mg) = 0.10 × algal biomass (mg)	Nauwerck (1963)
	Nauwerck used conversion number 1 to convert biovolume to biomass.	
8. Cell nitrogen to total cell carbon	Carbon (mg) = nitrogen (mg) × 6 ($\pm$2)	Strickland (1960) (marine)
	where nitrogen is measured as Kjeldahl nitrogen	

(Continued)

Table 1 (Continued)

Conversion	Formula and Comments	Reference
9. Cell phosphorus to total cell carbon	Carbon (mg) = phosphorus (mg) × 40 (±15)	Strickland (1960) (marine)
	where phosphorus is measured as organically combined phosphorus	
	Comment: This estimate of standing crop is a gross approximation due to the varying phosphorus content of algal cells. The cell content may vary up to fivefold, dependent upon the nutritional and physiological state of the cells.	
10. Chlorophyll to organic carbon	Carbon (mg) = F × chlorophyll (mg)	
	where	
	F = 30 for marine cultures and natural populations known to be without nutrient deficiencies	Strickland (1960) (marine)
	F = 60 for mixed freshwater lake populations	Wright (1959)
11. Chlorophyll to combined cell phosphorus	Phosphorus (mg) = 0.75 (±0.2) × chlorophyll (mg)	Strickland (1960) (marine)
12. Chlorophyll to cell nitrogen	Nitrogen (mg) = 7 (±3) × chlorophyll (mg)	Strickland (1960) (marine)
13. Chlorophyll *a* to gross primary productivity	Gross primary productivity (mg C/m^3)/hour = (30±20) × I × (mg chlorophyll *a*/m^3)	Strickland (1960) (marine)
	where	
	I is the intensity of daylight illumination in ly/min (3800-7200A)	
	Comment: There is evidence that Gross Primary Productivity is a crude function of the chlorophyll *a* content of the living phytoplankton in a water sample.	
	This expression should only be used to estimate gross primary productivity per unit volume and then only when I is below the "optimum" of about 0.1-0.15 ly/min.	

(Continued)

Table 1 (Continued)

Conversion	Formula and Comments	Reference
13. Chlorophyll *a* to gross primary Productivity (Cont'd)	Values for the factor can be anywhere between 10 and 100 with natural populations and there is some doubt as to whether the figure 30 has the significance of a "mean" value when any particular sea area is being studied. However, the use of a factor of 30 should enable an estimate to be made of the gross primary productivity of sea water to within ±70%, which may be of some value, especially in oligotrophic areas, when only plant pigment data are available. The above relationship tells nothing about the Net Primary Productivity of an area, unless respiration is known to be of minor importance.	
14. Chlorophyll to cell numbers	No. of cells = F × 10^6 × mg chlorophyll where F = 150 for *Chlamydomonas* = 2500 for *Chlorella* sp. = 13 for *Coscinodiscus radiatus* = 1800 for *Nitzschia closterium* = 58 for *Gymnodinium* sp. Comment: Several estimates have been made of the number of cells that contain unit weight of chlorophyll. No average figure has any significance but the above estimates for individual genera or species may be useful.	Strickland (1960)
15. Fresh weight to chlorophyll *a*	Chlorophyll *a* (mg) = F × fresh weight (mg) where F = 0.006 to 0.008 when the community is dominated by Cryptophyta F = 0.003 when the community is dominated by diatoms	Kalff and Knoechel (1978)
16. Dry weight to chlorophyll *a* (diatoms)	Chlorophyll *a* (mg) = F × dry weight (mg)	Verduin et al. (1976) (marine)

(Continued)

Table 1 (Continued)

Conversion	Formula and Comments	Reference
16. Dry weight to chlorophyll *a* (diatoms) (Cont'd)	where F = 0.120 when chlorophyll *a* concentrations are high (i.e., about 0.10 mg/l) or F = 0.480 when chlorophyll *a* concentrations are low (i.e., about 0.001 mg/l) Comment: Both values are based on diatom dominated marine phytoplankton communities.	
17. Dry weight to chlorophyll *a*	Chlorophyll *a* (µg/l) = F × dry weight (g) where F = 0.060 when chlorophyll *a* concentrations are high (i.e., about 0.10 mg/l) or F = 0.240 when chlorophyll *a* concentrations are low (i.e., about 0.001 mg/l) Comment: Both F values are based upon chlorophycean and cyanophycean dominated phytoplankton communities.	Verduin et al. (1976)
18. Dry weight to chlorophyll *a*	Chlorophyll *a* (mg) = F × dry weight (mg) where F = 0.23 for the entire phytoplankton community	Spangler (1969)
19. Ash-free dry weight to chlorophyll *a*	Chlorophyll *a* (µg/l) = 0.12 × ash-free weight (mg)	Wright (1959)
20. Dry weight to silica (diatoms)	Silica (mg) = (0.40 to 0.50) × dry weight (mg)	Lund (1964), Lund and Talling (1957)
21. Dry weight to cell nitrogen	Nitrogen (mg) = F × dry weight (mg) where F = 0.08 for blue-green algae F = < 0.08 for green algae F = < 0.04 for diatoms	Lund (1964)
22. Organic nitrogen to cell protein	Cell protein (mg) = 6.25 × organic nitrogen (mg)	Lund and Talling (1957)

(Continued)

Table 1 (Continued)

Conversion	Formula and Comments	Reference
23. Lake total phosphorus concentration to chlorophyll a (Cont'd)	$\text{Log}_{10}\underline{\text{chla}} = 1.449\ \text{Log}_{10}\ P - 1.136$ where P is the measured total phosphorus concentration (mg/m^3) and chla is the predicted chlorophyll a concentration (mg/m^3) Comment: This regression equation was based on data for 19 lakes in southern Ontario with nitrogen to phosphorus ratios greater than 12. Single measurements of total phosphorus were made at each lake during the spring overturn.	Dillon and Rigler (1974)
24. Lake total phosphorus to chlorophyll a	Log µg/liter chlorophyll a = 1.87 + 0.64 Log mg/l total phosphorus Comment: This regression equation was based upon 418 eastern lakes (r = 0.73). Data were averaged over 3 seasons (spring, summer, and fall).	Williams et al. (1978)
25. Lake total phosphorus to chlorophyll a	Log µg/liter chlorophyll a = 1.99 + 0.70 log mg/l total phosphorus Comment: This regression was based upon 318 eastern lakes with retention times greater than 14 days (r = 0.81). Data used for the regression were averaged over 3 seasons (spring, summer, and fall).	Williams et al. (1978)
26. Lake total phosphorus to chlorophyll a	Log µg/liter chlorophyll a = 3.29 + 1.36 log mg/l total phosphorus Comment: This regression was based upon 143 lakes of wide distribution (r = 0.95). Data used for the regression were averaged over 3 seasons (spring, summer, and fall).	Jones and Bachmann (1976)

(Continued)

Table 1 (Concluded)

Conversion	Formula and Comments	Reference
27. Lake total phosphorus to chlorophyll a (Cont'd)	Ln chlorophyll a (mg/m^3) = 1.449 Ln total phosphorus - 2442	Carlson (1977)
	Comment: This equation depends on the assumption that phosphorus is the major limiting factor for algal growth and that the concentrations of all forms of phosphorus present are a function of algal biomass.	
28. Lake total phosphorus to chlorophyll a	Log µg/liter chlorophyll a = 1.78 + 0.57 log mg/l TP	Lambou et al. (1976)
	Comment: Regression equation for 191 northeastern lakes (r = 0.74). Averaged chlorophyll a values were used in the regression.	
29. Lake total phosphorus to chlorophyll a	Log mg/l chlorophyll a = 1.95 + 0.68 log mg/l TP	Lambou et al. (1976)
	Comment: For all lakes with retention time > 14 days (N=131) (r = 0.84).	
30. Lake total phosphorus to biomass	Biomass ($\mu g/m^3$) = 1.206 log P (mg/m^3) + 1.635	Kalff and Knoechel (1978)
	where P is the mean summer total phosphorus concentration for the lake	
31. Lake total phosphorus to Secchi depth	Ln Secchi depth (m) = 3.87 - 0.98 Ln total phosphorus (mg/m^3)	Carlson (1977)
32. Particulate phosphorus to chlorophyll a	Log mg/l chlorophyll a = 2.36 + 0.75 log (TP-DP) mg/l	Lambou et al. (1976)
	Comment: For 131 northeastern lakes with retention times > 14 days.	
33. Chlorophyll a to Secchi depth	Ln Secchi depth (m) = 2.04 - 0.68 Ln chlorophyll a (mg/m^3)	Carlson (1977)
	Comment: The chlorophyll a - Secchi relationship is greatly influenced by the presence of inorganic mineral turbidity and by waters highly colored with dissolved substances.	

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Janik, Jeffrey J.
Estimating phytoplankton biomass and productivity : final report / by Jeffrey J. Janik, William D. Taylor (Department of Biological Sciences, University of Nevada, Las Vegas) Victor W. Lambou (Environmental Monitoring and Support Laboratory, U.S. Environmental Protection Agency, Las Vegas, Nev.). -- Vicksburg, Miss. : U.S. Army Engineer Waterways Experiment Station ; Springfield, Va. : available from NTIS, [1981].
16, 7 p. ; 27 cm. -- (Miscellaneous paper / U.S. Army Engineer Waterways Experiment Station ; E-81-2)
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"June 1981."
"Prepared for Office, Chief of Engineers, U.S. Army under Interagency Agreement No. WES-78-12, EWQOS Task IB.1."
"Monitored by Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss."
At head of title: Environmental and Water Quality

Janik, Jeffrey J.
Estimating phytoplankton biomass and productivity : ... 1981.
(Card 2)

Operational Studies.
Bibliography: p. 14-16.

1. Aquatic plants. 2. Phytoplankton. 3. Primary productivity (Biology). I. Taylor, William D. II. Lambou, Victor W. III. University of Nevada. Department of Biological Sciences. IV. United States. Environmental Protection Agency. Environmental Monitoring and Support Laboratory. V. United States. Army. Corps of Engineers. Office of the Chief of Engineers. VI. U.S. Army Engineer Waterways Experiment Station. Environmental Laboratory. VII. Environmental and Water Quality Operational Studies. VIII. Title IX. Series: Miscellaneous paper (U.S. Army Engineer Waterways Experiment Station) ; E-81-2.
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AD-A101 413 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG--ETC F/6 6/6
ESTIMATING PHYTOPLANKTON BIOMASS AND PRODUCTIVITY.(U)
JUN 81 J J JANIK, W D TAYLOR, V W LAMBOU
UNCLASSIFIED WES/MP/E-81-2 NL

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SUPPLEMENTARY

INFORMATION

DEPARTMENT OF THE ARMY
WATERWAYS EXPERIMENT STATION, CORPS OF ENGINEERS
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IN REPLY REFER TO: WESEV

21 October 1981

AD A101 413

Errata Sheet

No. 1

ENVIRONMENTAL & WATER QUALITY OPERATIONAL STUDIES

ESTIMATING PHYTOPLANKTON BIOMASS AND PRODUCTIVITY

Miscellaneous Paper E-81-2

June 1981

1. Page 5, paragraph 10: Change lines 3 and 4 of this paragraph to read

   that cell volume was better correlated to chlorophyll a and photosynthetic rates than to cell surface area and numerical abundance. Taylor

2. Page 8, paragraph 20: Change line 5 of this paragraph to read

   for estimating mean summer biomass (wet weight) from mean summer total phosphorus lake

3. Page 8, paragraph 20: Change the centered unnumbered equation in this paragraph to read

   $$\text{Log biomass } (\text{mg} \cdot 10^3/\text{m}^3) = 1.206 \log \text{phosphorus } (\text{mg}/\text{m}^3) + 1.635$$

4. Pages 14, 15, and 16: Replace these with the inclosed corrected pages.

5. Table 1, Sheets 2, 4, 5, and 7: Replace these with the inclosed corrected sheets

References

Antia, N. J., C. D. McAllister, T. R. Parsons, K. Stephens, and J. D. H. Strickland. 1963. Further measurements of primary production using a large volume plastic sphere. Limnol. Oceanogr. 8:166-183.

Beyers, R. J., J. Latimer, H. T. Odum, R. B. Parker, and N. E. Armstrong. 1963. Directions for determinations of changes in carbon dioxide concentration from changes in pH. Publ. Inst. Mar. Sci. Univ. Texas. 9:454-489.

Bunt, J. 1965. Measurements of photosynthesis and respiration in a marine diatom with the mass spectrometer and with carbon-14. Nature 207:1373-1375.

Carlson, R. E. 1977. A trophic state index for lakes. Limnol. Oceanogr. 22(2):361-369.

Dillon, D. J. and F. H. Rigler. 1974. The phosphorus chlorophyll relationship in lakes. Limnol. Oceanogr. 19:767-773.

Findenegg, I. 1965. Relationship between standing crop and primary productivity. In: Primary Productivity in Aquatic Environments. C. R. Goldman (ed.). Mem. Ist. Ital. Idrobiol. 18 Suppl., University of California Press, Berkeley. pp. 273-289.

Fogg, G. E. 1965. Algal cultures and phytoplankton ecology. University of Wisconsin Press, Madison, Wisconsin.

Fruh, E. G., H. M. Stewart, G. F. Lee, and G. A. Rohlich. 1966. Measures of eutrophication and trends. J. Wat. Pollut. Control Fed. 38(8): 1237-1258.

Jones, J. R. and R. W. Bachmann. 1976. Prediction of phosphorus and chlorophyll levels in lakes. J. Water Pollut. Control Fed. 48(9): 2176-2182.

Kalff, J. and R. Knoechel. 1978. Phytoplankton and their dynamics in oligotrophic and eutrophic lakes. Ann. Rev. Ecol. Syst. 9:475-495.

Lambou, V. W., L. R. Williams, S. C. Hern, R. W. Thomas, and J. D. Bliss. 1976. Prediction of phytoplankton productivity in lakes. In: Proceedings of the Conference on Environmental Modeling and Simulation, EPA 600-9/76-016. pp. 696-700.

Lund, J. W. G. 1964. Primary production and periodicity of phytoplankton Verh. Int. Ver. Limnol. 15:37-56.

Lund, J. W. G. and J. F. Talling. 1957. Botanical limnological methods with special reference to the algae. Bot. Rev. 23:489-583.

Mackereth, F. J. 1953. Phosphorus utilization by Asterionella formosa Hass. J. Exp. Bot. 4:296-313.

Mullin, M. M., P. R. Sloan, and R. W. Eppley. 1966. Relationship between carbon content, cell volume, and area in phytoplankton. Limnol. Oceanogr. 11(2):307-311.

Munawar, M. and A. Nauwerck. 1971. The composition and horizontal distribution of phytoplankton in Lake Ontario during the year 1970. In: Proc. 14th Conf. Great Lakes Res., Int. Assoc. Great Lakes Res. pp. 69-78.

Munawar, M., P. Stadelmann, and I. F. Munawar. 1974. Phytoplankton biomass, species composition and primary production at a nearshore and midlake station of Lake Ontario during IFYGL. Proc. 17th Conf. Great Lake Res. Internat. Assoc. Great Lakes Res. pp. 629-652.

Nalewajko, C. 1966. Dry weight, ash and volume data for some freshwater planktonic algae. J. Fish Res. Bd. Canada. 23(8):1285-1288.

Nauwerck, A. 1963. The relationships between zooplankton and phytoplankton in Lake Erken. Symb. Bot. Uppsal. 17(5):1-163.

Odum, E. P. 1971. Fundamentals of Ecology. Third Edition. W. B. Saunders Company, Philadelphia.

Paasche, E. 1960. On the relationship between primary production and standing stock of phytoplankton. J. Cons. Int. Explor. Mer. 26:33-48.

Rich, P. H. and R. G. Wetzel. 1978. Detritus in the lake ecosystem. The Amer. Natur. 112(982):57-71.

Rodhe, W., R. A. Vollenweider, and A. Nauwerck. 1958. The primary production and standing crop of phytoplankton. In: Perspectives in Marine Biology. A. A. Buzzati - Traverso (ed.). University of California Press, Berkeley. pp. 299-322.

Ryther, J. 1954. The ratio of photosynthesis to respiration in marine plankton algae and its effect upon the measurement of productivity. Deep-Sea Res. 2:134-139.

Ryther, J. H. and C. S. Yentsch. 1957. The estimation of phytoplankton production in the ocean for chlorophyll and light data. Limnol. Oceanogr. 2:281-286.

Smayda, T. J. 1965. A quantitative analysis of the phytoplankton of the Gulf of Panama II: On the relationship between C_{14} assimilation and diatom standing crop. Inter-American Tropical Tuna Commission Bulletin. 9(7):467-531.

Smayda, T. J. 1978. From phytoplankters to biomass. In: Phytoplankton Manual. A. Sournia (ed.). United Nations Educational, Scientific and Cultural Organization, Paris. pp. 273-279.

Soeder, C. J., J. F. Talling, and I. Baak. 1969. Dry weight and ash content. In: A Manual on Methods of Measuring Primary Production in Aquatic Environments. I.B.P. Handbook No. 12. Blackwell Scientific Publications, Oxford and Edinburgh. pp. 18-21.

Spangler, F. L. 1969. Chlorophyll and carotenoid distribution and phytoplankton ecology in Keystone Reservoir, Tulsa, Oklahoma. Ph.D. dissertation. Oklahoma State University.

Steemann-Nielson, E. 1963. Productivity, definition and measurement. In: The Sea, Vol 2. M. H. Hill (ed.). Interscience, New York. pp. 129-164.

Strathmann, R. E. 1967. Estimating the organic carbon content of phytoplankton from cell volume or plasma volume. Limnol. Oceanogr. 12(3): 411-418.

Strickland, J. D. H. 1960. Measuring the production of marine phytoplankton. Bulletin No. 122. Fish Res. Board of Canada, Queens Printer, Ottawa, Canada.

Taylor, W. D., L. R. Williams, S. C. Hern, and V. W. Lambou. 1979. Phytoplankton Water Quality Relationship in U. S. Lakes. Part VII. Comparison of some new and old indices and measurements of trophic state. EPA-600/3-79-079. U. S. Environmental Protection Agency, Las Vegas, Nevada.

Verduin, J., L. R. Williams, and V. W. Lambou. 1976. Components contributing to light extinction in natural waters: Method for isolation. U. S. Environmental Protection Agency. National Eutrophication Survey Working Paper No. 369.

Weber, C. I. (ed.). 1973. Biological field and laboratory methods for measuring the quality of surface waters and effluents. EPA-670/4-73-001. National Environmental Research Center Office of Research and Development, U. S. Environmental Protection Agency, Cincinnati, Ohio.

Williams, L. R., V. W. Lambou, S. C. Hern, and R. W. Thomas. 1978. Relationships of productivity and problem conditions to ambient nutrients: National Eutrophication Survey findings for 418 eastern lakes. EPA-600/3-78-002. U. S. Environmental Protection Agency, Las Vegas, Nevada.

Wright, J. C. 1959. Limnology of Canyon Ferry Reservoir. II. Phytoplankton standing crop and primary production. Limnol. Oceanogr. 4(3):235-245.

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Table 1 (Continued)

Conversion	Formula and Comments	Reference
4. Dry weight to cell carbon	Carbon (mg) = F × dry weight (mg)	
	where F is variously estimated by different workers and for different classes of algae, i.e.,	
	$F_{\text{diatom communities}} = 0.20 - 0.25$	Lund (1964), Antia et al. (1963)
	$F_{\text{nondiator. communities}} = 0.43 - 0.50$	Lund (1964), Verduin et al. 1976
5. Cell volume to cell carbon (non-diatoms)	$\text{Log}_{10} C = .76 \text{ Log}_{10} V - 0.29$	Mullin et al. (1966) (marine)
	where C is cell carbon in picograms and V is cell volume in μm^3	
	Comment: This formula was developed for use with preserved marine phytoplankton samples. This equation should not be used for diatoms because they have such a large vacuole and lower carbon per unit of cell volume. Conversion number 6 was developed for diatoms.	
6. Cell volume to cell carbon (diatoms)	$\text{Log}_{10} C = 0.712 \text{ Log}_{10} V - 0.314$	Strathmann (1967) (marine)
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7. Algal biomass to carbon	Carbon (mg) = 0.10 × algal biomass (mg)	Nauwerck (1963)
	Nauwerck used conversion number 1 to convert bio-volume to biomass.	
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(Continued)

Table 1 (Continued)

Conversion	Formula and Comments	Reference
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15. Fresh weight to chlorophyll *a*	Chlorophyll *a* (mg) = F × fresh weight (mg) where F = 0.006 to 0.008 when the community is dominated by Cryptophyta F = 0.003 when the community is dominated by diatoms	Kalff and Knoechel (1978)
16. Dry weight to chlorophyll *a* (diatoms)	Chlorophyll *a* (mg) = F × dry weight (g)	Verduin et al. (1976) (marine)

(Continued)

Table 1 (Continued)

Conversion	Formula and Comments	Reference
16. Dry weight to chlorophyll *a* (diatoms) (Cont'd)	where F = 0.120 when chlorophyll *a* concentrations are high (i.e., about 0.10 mg/l) or F = 0.480 when chlorophyll *a* concentrations are low (i.e., about 0.001 mg/l) Comment: Both values are based on diatom dominated marine phytoplankton communities.	
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21. Dry weight to cell nitrogen	Nitrogen (mg) = F × dry weight (mg) where F = 0.08 for blue-green algae F = < 0.08 for green algae F = < 0.04 for diatoms	Lund (1964)
22. Organic nitrogen to cell protein	Cell protein (mg) = 6.25 × organic nitrogen (mg)	Lund and Talling (1957)

(Continued)

Table 1 (Concluded)

	Conversion	Formula and Comments	Reference
	Lake total phosphorus to chlorophyll a (Cont'd)	Ln chlorophyll a (mg/m^3) = 1.449 Ln total phosphorus - 2.442 (mg/m^3)	Carlson (1977)
		Comment: This equation depends on the assumption that phosphorus is the major limiting factor for algal growth and that the concentrations of all forms of phosphorus present are a function of algal biomass.	
28.	Lake total phosphorus to chlorophyll a	Log µg/liter chlorophyll a = 1.78 + 0.57 log mg/l TP	Lambou et al. (1976)
		Comment: Regression equation for 191 northeastern lakes (r = 0.74). Averaged chlorophyll a values were used in the regression.	
29.	Lake total phosphorus to chlorophyll a	Log µg/l chlorophyll a = 1.95 + 0.68 log mg/l TP	Lambou et al. (1976)
		Comment: For all lakes with retention time > 14 days (N=131) (r = 0.84).	
30.	Lake total phosphorus to biomass (wet weight)	Log biomass ($mg \cdot 10^3/m^3$) = 1.206 log P (mg/m^3) + 1.635	Kalff and Knoechel (1978)
		where P is the mean summer total phosphorus concentration for the lake	
31.	Lake total phosphorus to Secchi depth	Ln Secchi depth (m) = 3.87 - 0.98 Ln total phosphorus (mg/m^3)	Carlson (1977)
32.	Particulate phosphorus to chlorophyll a	Log µg/l chlorophyll a = 2.36 + 0.75 log (TP-DP) mg/l	Lambou et al. (1976)
		Comment: For 131 northeastern lakes with retention times > 14 days.	
33	Chlorophyll a to Secchi depth	Ln Secchi depth (m) = 2.04 - 0.68 Ln chlorophyll a (mg/m^3)	Carlson (1977)
		Comment: The chlorophyll a - Secchi relationship is greatly influenced by the presence of inorganic mineral turbidity and by waters highly colored with dissolved substances.	

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ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MS
ENVIRONMENTAL LAB J J JANIK ET AL. JUN 81
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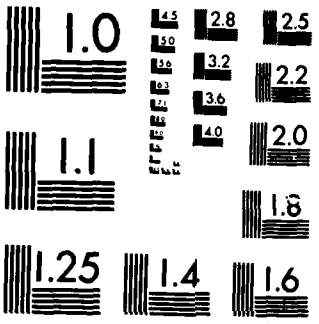

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

SUPPLEMENTARY

INFORMATION

DEPARTMENT OF THE ARMY
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REPLY TO
ATTENTION OF

WESEV-I

11 March 1985

AD-A101 413

Errata Sheet

No. 2

ENVIRONMENTAL & WATER QUALITY OPERATIONAL STUDIES

ESTIMATING PHYTOPLANKTON BIOMASS AND PRODUCTIVITY

Miscellaneous Paper E-81-2

June 1981

Table 1, Sheets 1-7: Replace with inclosed corrected sheets.

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Table 1

Annotated Conversion Table for Algae-Related Meausrements*

Conversion	Formula and Comments	Reference
1. Cell volume to biomass	1 mg dry weight = 1 mm^3 cell volume	Lund and Talling (1957)
	Algal biomass (mg) = algal cell volume (mm^3) x (1.00 ± 0.03)	Strickland (1960)
	Comment: The results of most surveys are expressed in terms of fresh weight (mg) where the approximate specific gravity of algae is assumed to be 1.0.	Rodhe et al. (1958)
2. Dry weight to ash-free dry weight	Ash-free dry weight (mg) = F x dry weight (mg)	
	where	
	F = 0.80 to 0.95 for individual green algal species	Nalewajko (1966)
	F = 0.70 to 0.90 for dinoflagellates	Strickland (1960) (marine)
	F = 0.45 to 0.73 for indvidual diatom species	Nalewajko (1966), Soeder et al. (1969)
3. Ash-free dry weight to cell carbon	Carbon (mg) = F x ash-free dry weight (mg)	
	where	
	F has been variously estimated by different workers, i.e.,	
	F = 0.53 ± 0.05	Lund and Talling (1957), Lund (1964)
	F = 0.40 - 0.60	Soeder et al. (1969)
	Comment: Cell carbon is one of the least variable constituents of algal cells. The percentage of carbon varies under unusual conditions, notably when photosynthesis continues under conditions of nitrogen deficiency.	

(Continued)

* Applies to freshwater algae unless noted otherwise.

Table 1 (Continued)

Conversion	Formula and Comments	Reference
4. Dry weight to cell carbon	Carbon (mg) = F x dry weight (mg)	
	where	
	F is variously estimated by different workers and for different classes of algae, i.e.,	
	$F_{\text{diatom communities}}$ = 0.20 - 0.25	Lund (1964), Antia et al. (1963)
	$F_{\text{nondiatom communities}}$ = 0.43 - 0.50	Lund (1964), Verduin et al. (1976)
5. Cell volume to cell carbon (nondiatoms)	$\text{Log}_{10}\ C = 0.76\ \text{Log}_{10}\ V - 0.29$	Mullin et al. (1966) (marine)
	where	
	C is cell carbon in picograms and V is cell volume in μm^3	
	Comment: This formula was developed for use with preserved marine phytoplankton samples. This equation should not be used for diatoms because they have such a large vacuole and lower carbon per unit of cell volume. Conversion number 6 was developed for diatoms.	
6. Cell volume to cell carbon (diatoms)	$\text{Log}_{10}\ C = 0.712\ \text{Log}_{10}\ V - 0.314$	Strathmann (1967) (marine)
	where	
	C is cell carbon in picograms and V is cell volume in μm^3	
7. Algal biomass to carbon	Carbon (mg) = 0.10 x algal biomass (mg)	Nauwerck (1963)
	Nauwerck used conversion number 1 to convert biovolume to biomass.	
8. Cell nitrogen to total cell carbon	Carbon (mg) = nitrogen (mg) x 6 (±2)	Strickland (1960) (marine)
	where nitrogen is measured as Kjeldahl nitrogen	

(Continued)

Table 1 (Continued)

Conversion	Formula and Comments	Reference
9. Cell phosphorus to total cell carbon	Carbon (mg) = phosphorus (mg) x 40 (±15) where phosphorus is measured as organically combined phosphorus Comment: This estimate of standing crop is a gross approximation due to the varying phosphorus content of algal cells. The cell content may vary up to fivefold, dependent upon the nutritional and physiological state of the cells.	Strickland (1960) (marine)
10. Chlorophyll to organic carbon	Carbon (mg) = F x chlorophyll (mg) where F = 30 is suggested for marine cultures and natural populations known to be without nutrient deficiencies	Strickland (1960) (marine)
11. Chlorophyll to combined cell phosphorus	Phosphorus (mg) = 0.75 (±0.2) x chlorophyll (mg)	Strickland (1960) (marine)
12. Chlorophyll to cell nitrogen	Nitrogen (mg) = 7 (±3) x chlorophyll (mg)	Strickland (1960) (marine)
13. Chlorophyll a to gross primary productivity	Gross primary productivity (mg C/m^3)/hour = (30±20) x I x (mg chlorophyll a/m^3) where I is the intensity of daylight illumination in ly/min (3800-7200A) Comment: There is evidence that gross primary productivity is a crude function of the chlorophyll a content of the living phytoplankton in a water sample. This expression should only be used to estimate gross primary productivity per unit volume and then only when I is below the "optimum" of about 0.1-0.15 ly/min.	Strickland (1960) (marine)

(Continued)

Table 1 (Continued)

Conversion	Formula and Comments	Reference
13. Chlorophyll *a* to gross primary productivity (Cont'd)	Values for the factor can be anywhere between 10 and 100 with natural populations and there is some doubt as to whether the figure 30 has the significance of a "mean" value when any particular sea area is being studied. However, the use of a factor of 30 should enable an estimate to be made of the gross primary productivity of sea water to within ±70%, which may be of some value, especially in oligotrophic areas, when only plant pigment data are available. The above relationship tells nothing about the net primary productivity of an area, unless respiration is known to be of minor importance.	
14. Chlorophyll to cell numbers	No. of cells = F x 10^6 x mg chlorophyll	Strickland (1960) citing others
	where	
	F = 150 for *Chlamydomonas*	
	= 2500 for *Chlorella* sp.	
	= 13 for *Coscinodiscus radiatus*	
	= 1800 for *Nitzschia closterium*	
	= 58 for *Gymnodinium* sp.	
	Comment: Several estimates have been made of the number of cells that contain unit weight of chlorophyll. No average figure has any significance but the above estimates for individual genera or species may be useful.	
15. Fresh weight to chlorophyll *a*	Chlorophyll *a* (mg) = F x fresh weight (mg)	Kalff and Knoechel (1978) citing others
	where	
	F = 0.006 to 0.008 when the community is dominated by Cryptophyta	
	F = 0.003 when the community is dominated by diatoms	
16. Dry weight to chlorophyll *a* (diatoms)	Chlorophyll *a* (mg) = F x dry weight (g)	Verduin et al. (1976) (marine)

(Continued)

Table 1 (Continued)

Conversion	Formula and Comments	Reference
16. Dry weight to chlorophyll *a* (diatoms) (Cont'd)	where F = 8.33 when chlorophyll *a* concentrations are high (i.e., about 0.10 mg/l), with a carbon:chlorophyll ratio of 30, or F = 2.08 when chlorophyll *a* concentrations are low (i.e., about 0.001 mg/l), with a carbon:chlorophyll ratio of 120 Comment: Both values are based on diatom dominated marine phytoplankton communities.	
17. Dry weight to chlorophyll *a*	Chlorophyll *a* (mg) = F x dry weight (g) where F = 16.7 when chlorophyll *a* concentrations are high (i.e., about 0.10 mg/l), with a carbon:chlorophyll ratio of 30, or F = 4.17 when chlorophyll *a* concentrations are low (i.e., about 0.001 mg/l), with a carbon:chlorophyll ratio of 120 Comment: Both F values are based upon chlorophycean and cyanophycean dominated phytoplankton communities.	Verduin et al. (1976)
18. Dry weight to chlorophyll *a*	Chlorophyll *a* (µg) = F x dry weight (mg) where F = 2.3 to 9.4 for the entire phytoplankton community	Spangler (1969)
19. Ash-free dry weight to chlorophyll *a*	Chlorophyll *a* (µg) = 8.3 x ash-free dry weight (mg)	Wright (1959)
20. Dry weight to silica (diatoms)	Silica (mg) = (0.40 to 0.50) x dry weight (mg)	Lund (1964)
21. Dry weight to cell nitrogen	Nitrogen (mg) = F x dry weight (mg) where F = 0.08 for blue-green algae F = <0.08 for green algae F = <0.04 for diatoms	Lund (1964)

(Continued)

Table 1 (Continued)

Conversion	Formula and Comments	Reference
22. Organic nitrogen to cell protein	Cell protein (mg) = 6.25 x organic nitrogen (mg)	Lund and Talling (1957)
23. Lake total phosphorus concentration to chlorophyll a	$\text{Log}_{10}\underline{\text{chla}} = 1.449\ \text{Log}_{10}\ P - 1.136$	Dillon and Rigler (1974)
	where P is the measured total phosphorus concentration (mg/m^3) and $\underline{\text{chla}}$ is the predicted chlorophyll a concentration (mg/m^3)	
	Comment: This regression equation was based on data for 19 lakes in southern Ontario with nitrogen to phosphorus ratios greater than 12. Single measurements of total phosphorus were made at each lake during the spring overturn.	
24. Lake total phosphorus to chlorophyll a	Log µg/liter chlorophyll a = 1.87 + 0.64 Log µg/l total phosphorus	Williams et al. (1978)
	Comment: This regression equation was based upon 418 eastern lakes (r = 0.73). Data were averaged over 3 seasons (spring, summer, and fall).	
25. Lake total phosphorus to chlorophyll a	Log µg/liter chlorophyll a = 1.99 + 0.70 log µg/l total phosphorus	Williams et al. (1978)
	Comment: This regression was based upon 318 eastern lakes with retention times greater than 14 days (r = 0.81). Data used for the regression were averaged over 3 seasons (spring, summer, and fall).	
26. Lake total phosphorus to chlorophyll a	Log µg/liter chlorophyll a = -1.09 + 1.46 log mg/l total phosphorus	Jones and Bachmann (1976)
	Comment: This regression was based upon 143 lakes of wide distribution (r = 0.95).	

(Continued)

Table 1 (Concluded)

Conversion	Formula and Comments	Reference
27. Lake total phosphorus to chlorophyll *a*	Ln chlorophyll *a* (mg/m^3) = 1.449 Ln total phosphorus (mg/m^3) - 2.442	Carlson (1977)
	Comment: This equation depends on the assumption that phosphorus is the major limiting factor for algal growth and that the concentrations of all forms of phosphorus present are a function of algal biomass.	
28. Lake total phosphorus to chlorophyll *a*	Log µg/liter chlorophyll *a* = 1.78 + 0.57 log mg/l TP	Lambou et al. (1976)
	Comment: Regression equation for 191 northeastern lakes (r = 0.74). Averaged chlorophyll *a* values were used in the regression.	
29. Lake total phosphorus to chlorophyll *a*	Log µg/l chlorophyll *a* = 1.95 + 0.68 log mg/l TP	Lambou et al. (1976)
	Comment: For all lakes with retention time > 14 days (N=131) (r = 0.84).	
30. Lake total phosphorus to biomass (wet weight)	Log biomass (g/m^3) = 1.206 log P (mg/m^3) + 1.635	Kalff and Knoechel (1978)
	where P is the mean summer total phosphorus concentration for the lake	
31. Lake total phosphorus to Secchi depth	Ln Secchi depth (m) = 3.87 - 0.98 Ln total phosphorus (mg/m^3)	Carlson (1977)
32. Particulate phosphorus to chlorophyll *a*	Log µg/l chlorophyll *a* = 2.36 + 0.75 log (TP-DP) mg/l	Lambou et al. (1976)
	Comment: For 131 northeastern lakes with retention times > 14 days.	
33. Chlorophyll *a* to Secchi depth	Ln Secchi depth (m) = 2.04 - 0.68 Ln chlorophyll *a* (mg/m^3)	Carlson (1977)
	Comment: The chlorophyll *a* - Secchi relationship is greatly influenced by the presence of inorganic mineral turbidity and by waters highly colored with dissolved substances.	

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